# Pilot Testing of Mercury Oxidation Catalysts for Upstream of Wet FGD Systems

## Quarterly Technical Progress Report

## April 1, 2006 – June 30, 2006

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**Cooperative Agreement No: DE-FC26-04NT41992**

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## DISCLAIMER

## ABSTRACT

This document summarizes progress on Cooperative Agreement DE-FC26-04NT41992, "Pilot Testing of Mercury Oxidation Catalysts for Upstream of Wet FGD Systems," during the time-period April 1 through June 30, 2006. The objective of this project is to demonstrate at pilot scale the use of solid honeycomb catalysts to promote the oxidation of elemental mercury in flue gas from coal combustion, and the use of a wet flue gas desulfurization (FGD) system downstream to remove the oxidized mercury at high efficiency. The project is being co-funded by the U.S. DOE National Energy Technology Laboratory, EPRI, Great River Energy (GRE), TXU Generation Company LP, the Southern Company, Salt River Project (SRP) and Duke Energy. URS Group is the prime contractor.

The mercury control process under development uses honeycomb catalysts to promote the oxidation of elemental mercury in the flue gas from coal-fired power plants that have wet lime or limestone FGD systems. Oxidized mercury is removed in the wet FGD absorbers and leaves with the byproducts from the FGD system. The current project is testing previously identified catalyst materials at pilot scale and in a commercial form to provide engineering data for future full-scale designs. The pilot-scale tests will continue for approximately 14 months or longer at each of two sites to provide longer-term catalyst life data. A new, third site will test catalysts for a period of 12 months. Pilot-scale wet FGD tests are being conducted periodically at each site to confirm the ability to scrub the catalytically oxidized mercury at high efficiency.

This is the tenth reporting period for the subject Cooperative Agreement. During this period, project efforts included ongoing operation of the catalyst pilot units at the TXU Generation Company LP's Monticello Steam Electric Station and at Georgia Power's Plant Yates. One catalyst activity measurement trip was made to Monticello and two catalyst activity measurement trips were made to Plant Yates during the quarter. Also during the quarter, a third pilot unit was started up at SRP's Coronado Station. Initial catalyst performance results were measured there, and the pilot wet FGD system was operated downstream of one of the catalysts installed in that pilot unit. This Technical Progress Report presents and discusses results from these three pilot units from the current quarter.

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## INTRODUCTION

This document is the quarterly Technical Progress Report for the project "Pilot Testing of Mercury Oxidation Catalysts for Upstream of Wet FGD Systems," for the time-period April 1 through June 30, 2006. The objective of this project is to demonstrate at pilot scale the use of solid honeycomb catalysts to promote the oxidation of elemental mercury in flue gas from coal combustion, and a wet flue gas desulfurization (FGD) system downstream of the catalysts to remove the oxidized mercury at high efficiency. The project is co-funded by the U.S. DOE National Energy Technology Laboratory (NETL), EPRI, Great River Energy (GRE), TXU Generation Company LP (TXU Generation), Southern Company, Salt River Project (SRP) and Duke Energy. URS Group is the prime contractor.

The mercury control process under development uses honeycomb catalysts to promote the oxidation of elemental mercury in the flue gas from coal-fired power plants that have wet lime or limestone FGD systems. Oxidized mercury is removed in the wet FGD absorbers and leaves with the byproducts from the FGD system. The current project is testing previously identified catalyst materials at pilot scale and in a commercial form, to provide engineering data for future full-scale designs. The pilot-scale tests will continue for approximately 12 to14 months at each of three sites to provide catalyst life data.

Pilot-scale wet FGD tests are being conducted periodically at each site to confirm the ability to scrub the catalytically oxidized mercury at high efficiency. The pilot wet FGD system has also been used downstream of catalysts tested as part of another cooperative agreement (DE-FC26-01NT41185).

Five utility team members have provided project host sites for mercury oxidation catalyst testing. GRE provided a test site at their Coal Creek Station (CCS), which fires North Dakota lignite, and CPS Energy of San Antonio (CPS) provided a test site at their J.K. Spruce Plant, which fires Powder River Basin (PRB) subbituminous coal. Both the CCS and Spruce mercury oxidation catalyst pilot tests were conducted as part of project 41185, and both hosted pilot FGD tests downstream of the catalysts as part of the current, 41992 project.

In the current project, TXU Generation is hosting pilot catalyst tests and intermittent wet FGD pilot tests at their Monticello Steam Electric Station, Unit 3, which fires a Texas lignite/Powder River Basin (PRB) coal blend. The TXU Generation test program began in mid-January 2005.

Duke Energy was also to host oxidation catalyst pilot and wet FGD pilot tests at one of their sites firing low-sulfur Eastern bituminous coal. However, both of their candidate sites (that are having wet FGD retrofitted but not selective catalytic reduction [SCR]) were measured to have low elemental mercury concentrations in the flue gas downstream of the particulate control device. Consequently, Duke Energy decided not to host oxidation catalyst pilot tests. However, they did host pilot wet FGD tests to determine the ability to scrub the highly oxidized mercury content of the particulate control outlet flue gas at their Marshall Station.

Southern Company has a number of generating units that fire low-sulfur Eastern bituminous coal. They agreed to host oxidation catalyst tests at their Georgia Power Plant Yates, Unit 1, and

to provide project co-funding. Oxidation catalyst pilot tests commenced there on December 16, 2005.

SRP has recently joined the 41992 project to test low-temperature oxidation catalysts upstream of the wet FGD system at their Coronado Station, which fires low-sulfur Powder River Basin coal. They built a pilot unit that has two catalyst chambers, and are testing gold catalysts at two velocities. This pilot unit started up on March 30, 2006, and initial performance results were measured during the current quarter.

This report presents results from this project for the second quarter of calendar year 2006. The remaining report is divided into five sections: an Executive Summary followed by a section that describes Experimental procedures, then sections for Results and Discussion, Conclusions, and References.

# EXECUTIVE SUMMARY

## Summary of Progress

The current reporting period, April 1 through June 30, 2006, is the tenth technical progress report period for this project. During the current period, the oxidation catalyst pilot units continued in operation both at Monticello Unit 3 and at Georgia Power's Plant Yates, Unit 1. One catalyst activity measurement trip was made to the Monticello site at the end of the quarter, but otherwise access to the pilot unit was restricted due to construction activity overhead. At Plant Yates, two catalyst activity measurement trips were made. Also during the quarter, pilot catalyst testing began at SRP's Coronado Station, and wet FGD pilot tests were conducted downstream of one of the two catalysts installed in that pilot unit.

## Problems Encountered

The most significant problem during the current period was that overhead construction activity in the vicinity of the oxidation catalyst pilot unit at Monticello severely limited project team access to the unit. As a result, catalyst activity measurements could not be made at that site until the final week of the quarter. Both the Monticello and Yates pilot units unscheduled outages during the quarter, primarily due to interruption in power to the control cabinet for the pilot skids. There were no other significant problems encountered during the current reporting period other than technical issues that are discussed later in this report.

## Plans for Next Reporting Period

During the next reporting period (July 1 through September 30, 2006), catalysts will be evaluated for elemental mercury oxidation activity at Monticello and at Plant Yates through routine (~bimonthly) evaluation trips. Ontario Hydro relative accuracy tests and final wet FGD pilot testing will occur at Monticello during the quarter. The 14-month pilot unit operation period at Monticello was to end in March. However, because of unscheduled pilot unit outage time in late December through mid-January, and due to very limited access to the pilot unit during the current and previous quarter due to overhead construction, the shutdown has been delayed until the next quarter. At Plant Yates, intensive gas characterization efforts will occur during the quarter. The catalyst pilot unit at SRP Coronado will continue in operation, and one catalyst activity test will be conducted.

## Prospects for Future Progress

During the subsequent reporting period (October 1 through December 31, 2006), the oxidation catalyst pilot unit at Monticello should be shut down. At Plant Yates, oxidation catalysts will be evaluated for elemental mercury oxidation activity through routine (~bimonthly) evaluation trips. The fourth oxidation catalyst will likely be installed in the pilot unit, and initial wet FGD pilot testing will likely occur at Plant Yates. Pilot unit operation will continue at Plant Yates until the first quarter of calendar year 2007. The catalyst pilot unit at SRP Coronado will continue in operation, and one catalyst activity test will be conducted. The SRP Coronado pilot unit is scheduled to remain in operation through the end of March 2007.

## EXPERIMENTAL

The work being conducted as part of this project will use three different experimental apparatus types. One is an elemental mercury catalyst oxidation pilot unit (8000 acfm of flue gas treated), the first of which was recently installed at TXU Generation's Monticello Steam Electric Station. A second, nearly identical pilot unit was previously located at CPS' Spruce Plant. During the course of this project, this second pilot unit has been relocated and installed at Georgia Power's Plant Yates.

Each pilot unit has four separate compartments that allow four different catalysts to treat flue gas from downstream of the host plant's particulate control device. Details of the pilot unit design, construction, catalyst preparation and pilot unit operation have been discussed in previous quarterly technical progress reports for the 41185 project[1, 2, 3, 4].

The second pilot unit, which has now been installed and placed in service at Plant Yates, did not have sonic horns installed on it while it was in operation at CPS' Spruce Plant. Spruce has a fabric filter for particulate control and sonic horns were not needed to keep the catalyst clean. In anticipation of operating downstream of a small-SCA ESP at Plant Yates, new sonic horns were installed prior to shipping the pilot unit. The first pilot unit, at Monticello, has 17-inch horns that were supplied by Analytec Corporation. Since those horns were procured, Analytec was purchased by BHA, who markets a similar horn of their own design. Consequently, the second pilot unit had BHA rather than Analytec horns installed.

Recently, a third pilot unit was built by SRP for catalyst testing at their Coronado Station. The pilot unit has two rather than four chambers, with each sized to treat 2000 acfm of flue gas. The pilot unit operates on a slipstream of flue gas from downstream of the air heater and upstream of the wet FGD system on a unit that has a hot-side ESP for particulate control. BHA sonic horns were installed to help prevent fly ash buildup. The host unit fires Powder River Basin coal.

The activity of the catalysts is determined by measuring the change in elemental mercury concentration across each catalyst while ensuring that the total mercury concentrations do not change significantly across the catalyst. These measurements are primarily conducted using a mercury semi-continuous emissions monitor (SCEM) developed with funding from EPRI. The analyzer has been described in a previous report[5]. Periodically, the analyzer results are verified by conducting manual flue gas sampling efforts in parallel across each catalyst chamber by the Ontario Hydro method.

The flue gas sampling system for the second pilot unit was modified prior to shipping to Plant Yates to allow the possibility of using two SCEMs to simultaneously sample catalyst inlet and outlet flue gas. Originally, both pilot units were equipped with a sampling manifold and solenoid valves that selected flue gas from the catalyst inlet or the outlet of any of the four catalyst chambers. One analyzer could be cycled to analyze flue gas from any of these five locations. The selected flue gas sample was then drawn through an inertial gas separator (IGS) filter by a centrifugal blower, and the gas sample to the SCEM was withdrawn radially from the IGS filter. With the modification to the second pilot unit, it now has two IGS filters and two blowers, one dedicated to pilot unit inlet flue gas and the second connected via manifold and solenoid valves

to the outlets of the four catalyst chambers. This allows the use of two analyzers to simultaneously analyze catalyst inlet and outlet flue gas. If only one analyzer is used, the flue gas sample line will have to be physically moved from the inlet to the outlet sampling loops to quantify catalyst performance. The third pilot unit at SRP Coronado is also set up to sample in this manner.

The second experimental apparatus used as part of this project is a bench-scale test unit that is used to evaluate the activity of candidate catalyst samples under simulated flue gas conditions. The bench-scale catalyst oxidation test apparatus was previously described in quarterly technical progress reports for the 41185 project[3, 4].

The third experimental apparatus is a pilot-scale wet FGD unit that was designed and fabricated as part of the current project to allow the measurement of how effectively catalytically oxidized mercury can be scrubbed. The pilot unit was designed to scrub the flue gas from one of four catalyst chambers on either of the mercury oxidation catalyst pilot units. The design basis and a simplified piping and instrumentation diagram (P&ID) for the pilot wet FGD system were included in a previous technical progress report for this project.[6]

# RESULTS AND DISCUSSION

This section provides details of technical results available from the current reporting period, April 1 through June 30, 2006. Pressure drop data and catalyst activity data are presented for the catalysts installed in the catalyst pilot unit at Monticello. No catalyst activity results are available for the Monticello pilot unit for most of the quarter because of limited access to the site during overhead construction activities. A measurement trip was conducted there during the last week of the quarter. Catalyst activity and pressure drop results are available from two measurement trips to the pilot unit at Plant Yates during the quarter. Finally, catalyst activity results and the results of wet FGD testing downstream of one of the two catalysts are presented for the pilot unit at SRP Coronado Station. The available results from each pilot unit are presented and discussed in separate subsections below.

## Catalyst Pilot Unit Operation at Monticello Station

The catalyst pilot unit was started up in flue gas service at Monticello Steam Electric Station, near Mount Pleasant, Texas, on January 14, 2005. It has operated continuously since then other than during short, unscheduled host unit outages and unscheduled pilot unit outages as described below. The physical characteristics of the four catalysts installed there are summarized in Table 1.

**Table 1. Characteristics of Catalysts Installed in Pilot Unit at Monticello**

| Catalyst Box Number | Catalyst (Source) | Cross Section, in x in (m x m) | Catalyst Depth | Cell Pitch, mm | Cells per Sq. In. (CPSI) | Area Velocity, std. ft/hr |
|---|---|---|---|---|---|---|
| 1 | Pd #1 (Johnson Matthey) | 29.5 x 29.5 (0.75 x 0.75) | 9 in. (0.23 m) | 3.2 | 64 | 52 |
| 2 | SCR (Cormetech/MHI) | 35.4 x 36.2 (0.90 x 0.92) | 29.5 in. (0.75 m) | 3.3 | 58 | 11 |
| 3 | Gold (Sud-Chemie Prototech) | 29.5 x 29.5 (0.75 x 0.75) | 3 x 3 in. (3 x 0.08 m) | 3.2 | 64 | 52 |
| 4 | Pd #1 (regenerated from CCS) | 29.5 x 29.5 (0.75 x 0.75) | 3 x 3 in. (3 x 0.08 m) | 3.2 | 64 | 52 |

### *Catalyst Pressure Drop Performance*

In previous catalyst testing at CCS, fly ash was observed to build up in the horizontal-gas-flow catalyst cells, resulting in increased catalyst pressure drop and decreased catalyst mercury oxidation performance. Subsequently, sonic horns were installed and were generally effective in preventing fly ash buildup. Since Monticello, like CCS, has an ESP for particulate control

(Spruce has a reverse-gas fabric filter), it was expected that the sonic horns would be necessary to prevent fly ash buildup there.

Figure 1 shows the "full load" pressure drop data for all four catalysts from start up through the current quarter. In the figure, "full load" is defined as periods where the flue gas flow rate through each catalyst (gold) was at least 1500 acfm. The desired flow rate is 2000 acfm for all four catalysts, but cannot always be achieved due to limited ID fan draft at lower load and the relatively high pressure drop across some of the catalysts. Also, during the current period, the flue gas flow through three of the four catalysts was restricted due to inadequate instrument air pressure to the flow control valves downstream of the catalyst compartments.

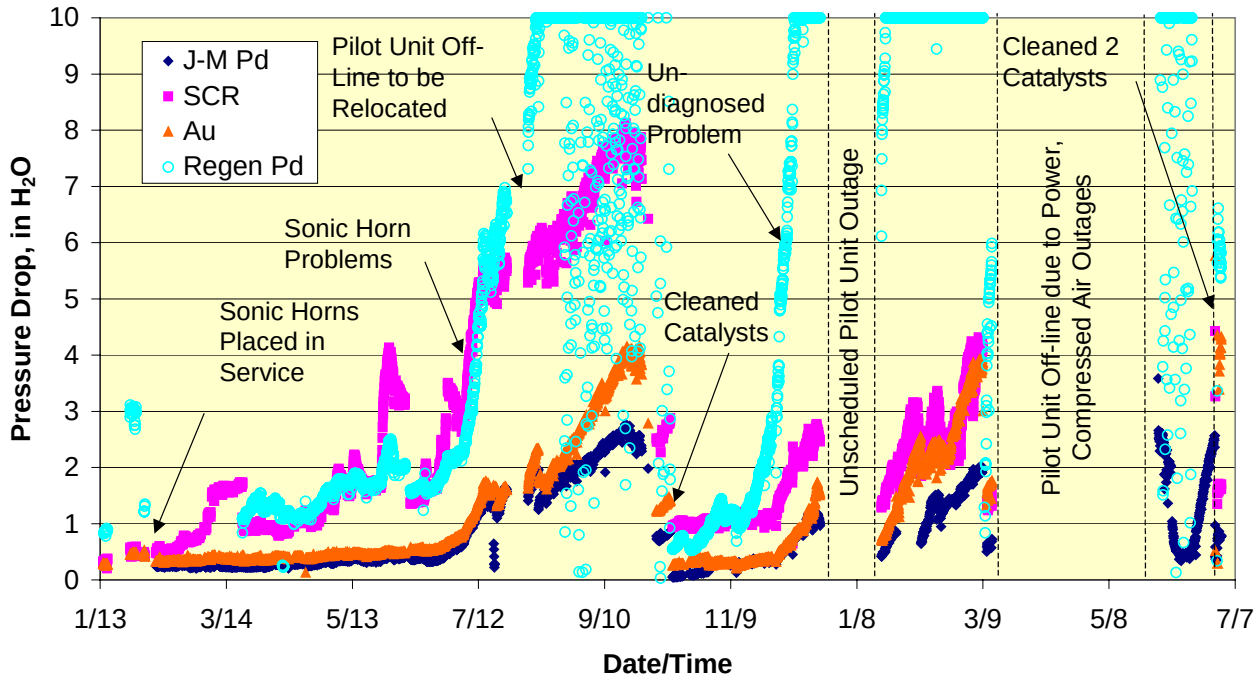


**Figure 1. Full-load Catalyst Pressure Drop Data from Monticello Pilot Unit**

The sonic horns were placed in service on the Monticello catalyst pilot unit two weeks after initial pilot unit startup on January 14, 2005. However, the sonic horns did not operate properly through the remainder of that quarter. During that period, a failed compressed air pipe nipple was replaced, the horn timer was replaced, the solenoid valves controlling air flow to the horns were replaced, the horns were disassembled and cleaned, and an air pressure regulator was installed to ensure that the optimum air pressure of 70 psig was supplied to the horns. While these efforts corrected a number of operational issues, it still remained that the solenoid valves controlling air flow to the horns did not turn off properly at the end of their cycle (each horn is intended to sound 10 seconds every half hour).

In April 2005, one solenoid valve that had been particularly problematic was replaced with a larger valve (3/4-inch vs. ¼-inch). This change, along with minor wiring and tubing changes, resulted in all four valves cycling properly beginning in late April. The four horns appear to have cycled properly through approximately mid-June 2005.

The pressure drop across all four catalysts increased significantly starting in mid-June, again apparently caused by sonic horn malfunction. Although the air line to the sonic horns has a regulator and filter to control the air pressure and to remove impurities from the compressed air, the air line upstream of the regulator is rusty on the inside. During continued horn operation, exfoliated rust particles from the line tend to build up in the regulator inlet, eventually plugging air flow to the regulator. The regulator was found plugged and was cleaned twice over the summer of 2005.

The pressure drop across all four catalysts dropped somewhat at the beginning of October, due to the effects of a short unit outage. However, in early October it became apparent that although proper sonic horn operation was restored, the fly ash buildup in the catalyst cells would not be removed and the pressure drop across the catalysts would not be restored to clean conditions solely through sonic horn operation. Consequently, the pilot unit was shut down on October 11 and all four chambers were cleaned of fly ash buildup with compressed air and a shop-type vacuum. Considerable fly ash buildup was removed from all four catalysts. Catalyst chamber 1 (Johnson Matthey Pd) had a buildup of hardened fly ash on the chamber floor just upstream of the catalyst, which was evidence of moisture having entered that chamber. While the catalyst chambers were open, the lines to the pressure drop transducers were cleaned out, and the transducers were "zeroed." Plugged, or partially plugged pressure drop tubing connections were found at the inlets to several of the catalyst boxes, and may have contributed to erroneous pressure drop readings. Also during the quarter, a basket strainer was installed on the air line upstream of the regulator in an effort to prevent future plugging of the regulator.

At startup on October 12, after the catalysts were cleaned, the pressure drop across all four catalysts was markedly reduced. The pressure drop values across the gold and Johnson Matthey Pd were between 0.1 and 0.2 in. $H_2O$, and the pressure drop across the regenerated Pd from CCS was 0.55 in. $H_2O$. The highest pressure drop was across the SCR catalyst, at 0.9 in. $H_2O$. This is not surprising considering its longer, 29.5-in. catalyst length (the others are at 9-inches of total catalyst length).

In late November, the pressure drop across the regenerated Pd catalyst was observed to increase. URS personnel were on site conducting another project, and observed sonic horn operation on the catalyst pilot unit on November 30$^{th}$. All four horns appeared to be cycling and sounding properly, and the compressed air pressure to each was at least 70 psig, the design value, during horn operation. It was decided to continue operation of the pilot unit with no changes and observe the pressure drop values.

On December 2$^{nd}$, the pressure drop across the other four catalysts began to rise, while the pressure drop across the regenerated Pd catalyst continued to increase towards 10 in. $H_2O$, the maximum transducer reading. URS personnel were again on site and observed sonic horn operation during the week of December 12$^{th}$. The solenoid valve for the horn on the gold catalyst

chamber was found to not fully close at the end of its cycle, causing that horn to blow continuously. However, even with that horn blowing continuously, the air pressure to the other horns when they operated was observed to be 68 psig, which is near the ideal pressure of 70 psig. The air pressure regulator setting was increased to produce 70 psig at the horns with two in operation, and the horn on the gold catalyst chamber was left blowing all of the time.

On December 21 flue gas flow to the pilot skid was stopped for what were then unknown reasons. As a result of holiday and vacation schedules, this unplanned shutdown of the pilot unit was not diagnosed and corrected until early in the current quarter. The cause was traced to damage to the instrument air line to the pilot unit caused by debris falling from overhead construction, which in turn caused the air-operated flow control valves to fail closed. The line was repaired and the pilot unit came back on line on January 19, 2006.

Further troubleshooting was conducted in mid-February to diagnose the pressure drop increases observed. This trip showed no outward signs of a problem – the sonic horns were observed to cycle properly, all pressure drop tubing was clear, and the transducers zeroed properly. Due to the construction activity in the vicinity of the pilot unit, it was not possible to shut down and open any of the catalyst chambers to observe the fly ash buildup.

During the previous quarter, telephone communications with the pilot unit data logger were lost, and communications were not restored until the last week of the current quarter due to restricted access to the pilot unit during overhead construction activities. From mid-February through March 7, the last day before telephone communications with the pilot unit was lost, the pressure drop across the regenerated Pd catalyst remained off scale at greater than 10 in. $H_2O$, while the pressure drops across the other three catalysts remained elevated, in the range of 1.5 to 4 in. $H_2O$.

After March 7, telephone communications with the pilot unit was lost for then unknown reasons, so it was not known if the pressure drop values remained steady or increased further. These data were recovered during a catalyst activity measurement trip the last week of the current quarter. The data show that on March 9, the pilot unit flue gas flow rate was greatly reduced, possibly due to low unit load. After full flow was restored, late on March 10, the pressure drops across all four catalysts were reduced, with the regenerated Pd catalyst pressure drop ranging from 4 to 6 in. $H_2O$ and the pressure drop across the other three ranging from 0.5 to less than 2 in. $H_2O$. This "recovery" has been seen before when the sonic horns continue to operate while the flue gas flow rate is greatly reduced.

The pilot unit was brought off line on March 13 while the power to that area was disconnected, and it remained off line through May 31. Although power was restored on May 31, the instrument air supply to the pilot unit was inadequate for all four catalyst box flow control valves to operate properly. For this reason, only the Johnson Matthey catalyst saw normal flue gas flow; the other three saw little or no flow.

The low air pressure problem was discovered the last week of June, when project team members were first allowed back on site to make measurements. When flow was restored, it was observed that the pressure drops across the regenerated Pd and SCR catalysts were high (>4 in $H_2O$), while the pressure drops across the gold and JM Pd appeared to be normal. It was decided to shut

down and manually clean the regenerated Pd and SCR catalysts with compressed air, but not the gold and JM Pd. After cleaning those two catalysts and starting back up, the pressure drop across the SCR catalyst was lowered to less than 2 in $H_2O$, but the regenerated Pd remained above 5 in $H_2O$.

Also, when the pilot unit was started back up after cleaning the two catalysts and flue gas flow rates were stabilized at 2000 acfm through each, the pressure drop across the gold catalyst was observed to be higher than thought, at 4 in $H_2O$. There was not time during this one-week measurement trip to go back and clean the gold catalyst, but a return trip to clean the gold catalyst and check the JM Pd is planned.

### *Elemental Mercury Oxidation Activity Performance*

Because of the restricted access to the Monticello oxidation catalyst pilot unit, the elemental mercury oxidation activity of these four catalysts was not measured until the last week of the quarter, after the regenerated Pd and SCR catalysts had been manually cleaned of fly ash buildup. The results of these measurements are summarized in Table 2.

**Table 2. Results of Catalyst Activity Measurements at Monticello, June 28-30, 2006**

| Catalyst Type | Catalyst Inlet Total Hg* ($\mu g/Nm^3$) | Catalyst Inlet Elemental Hg* ($\mu g/Nm^3$) | Catalyst Inlet Oxidation (%) | Catalyst Outlet Total Hg* ($\mu g/Nm^3$) | Catalyst Outlet Elemental Hg* ($\mu g/Nm^3$) | % Hg Adsorption Across Catalyst | Oxidation Across Catalyst (%) | Catalyst Outlet Oxidation (%) |
|---|---|---|---|---|---|---|---|---|
| JM Pd | 13.4 | 6.2 | 54 | 14.4 | 5.5 | -7% | 11 | 62 |
| SCR | 11.5 | 6.2 | 47 | 17.2 | 4.2 | -45% | 33 | 72 |
| Gold | 14.5 | 6.1 | 58 | 14.2 | 3.9 | 2% | 36 | 72 |
| Regen. Pd | 15.1 | 5.0 | 67 | 11.3 | 2.1 | 25% | 57 | 81 |

*1 $\mu g/Nm^3$ @ 3% $O_2$ = 0.67 lb $Hg/10^{12}$ Btu heat input

The results show that all four catalysts have lost a significant amount of activity for elemental mercury oxidation, in a total of 13 to 14 months of flue gas exposure. This is illustrated in Figure 2. It is somewhat surprising that the regenerated palladium catalyst was measured to be the most active, as the gold has typically been the most active in previous measurements. However, as described above, the regenerated palladium had just been cleaned of fly ash buildup while the gold was not. In the near future the gold will also be cleaned of fly ash buildup and activity will be measured for the cleaned catalyst.

Also, it is not known how the unscheduled outage of this pilot unit affected catalyst activity. It can only be speculated that several instances of having flue gas flue interrupted for extended periods, without having the opportunity to purge the catalyst compartments with dry air, has adversely affected the catalysts.

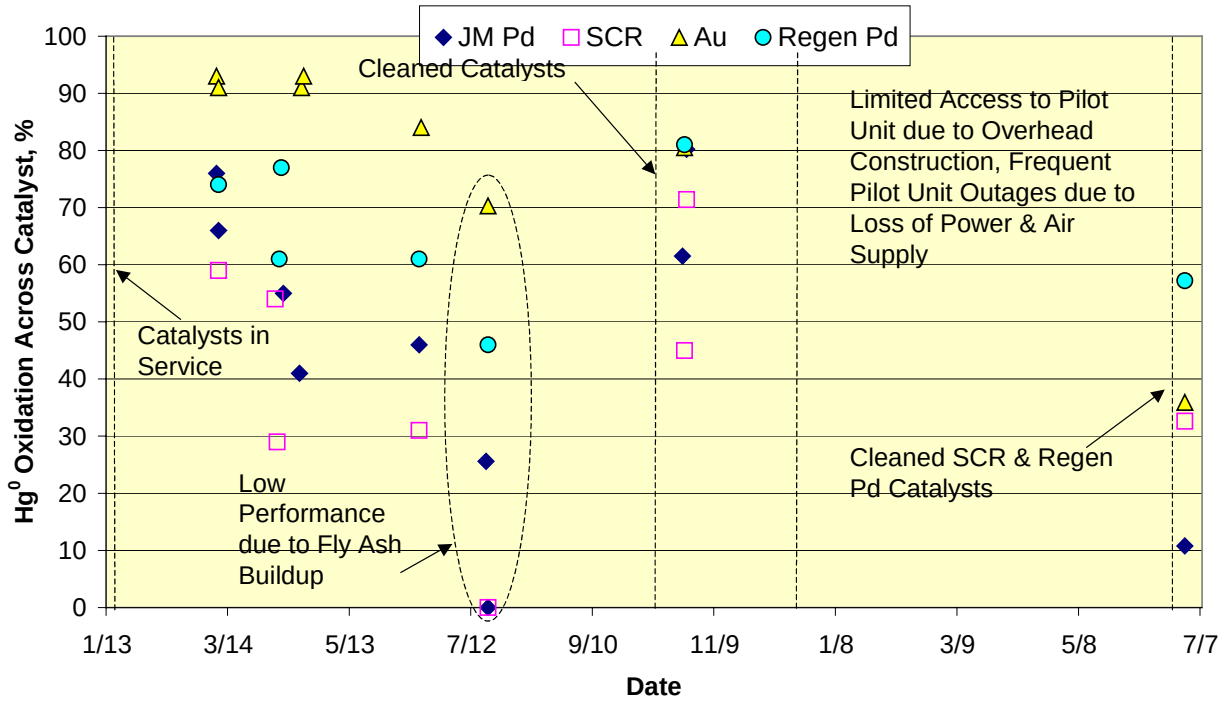


**Figure 2. Activity versus Time for the Oxidation Catalysts at Monticello Station**

## Catalyst Pilot Unit Operation at Plant Yates

The catalyst pilot unit that was previously in service at Spruce Plant as part of project DE-FC26-01NT41185 was shipped to Plant Yates in September 2005 and installed downstream of the ID fan on Unit 1. The unit had an extended outage from October 1 through November 20, so startup was delayed until December 2005.

The catalyst pilot unit was shipped with two of the regenerated catalysts from the Spruce Plant testing (gold and SCR) still in place. Two new catalyst charges from Sud-Chemie Prototech (gold and Pd) were installed in the pilot unit the week of December 12. The physical characteristics of the four catalysts currently installed are summarized in Table 3.

Flue gas flow was established on December 16, 2005. Because of the upcoming Christmas and New Year's holidays, the pilot unit was left in operation, including operation of sonic horns on each compartment, but initial catalyst activity measurements were delayed until January 2006. A second set of measurements was made in February 2006. Two catalyst measurement trips were conducted during the current quarter, in April and June 2006.

**Table 3. Characteristics of Catalysts Installed in Pilot Unit at Plant Yates**

| Catalyst Box Number | Catalyst | Cross Section, in x in (m x m) | Catalyst Depth | Cell Pitch, mm | Cells per Sq. In. (CPSI) | Area Velocity, std. ft/hr |
|---|---|---|---|---|---|---|
| 1 | Pd #1 (Sud-Chemie Prototech) | 29.5 x 29.5 (0.75 x 0.75) | 3 x 3 in. (3 x 0.08 m) | 3.2 | 64 | 52 |
| 2 | Gold (Sud-Chemie Prototech) | 29.5 x 29.5 (0.75 x 0.75) | 3 x 3 in. (3 x 0.08 m) | 3.2 | 64 | 52 |
| 3 | Gold (regenerated from Spruce Plant) | 29.5 x 29.5 (0.75 x 0.75) | 3 x 3 in. (3 x 0.08 m) | 3.2 | 64 | 52 |
| 4 | Argillon SCR (regenerated from Spruce Plant) | 35.4 x 35.4 (0.90 x 0.90) | 29.5 in. (0.75 m) | 3.7 | 46 | 13 |

### *Catalyst Pressure Drop Data*

The catalyst pilot unit at Plant Yates is equipped with a data logger, but until recently no phone line was available nearby. From December 2005 through June 2006, the approach for tracking pilot unit conditions was to download data to a flash drive whenever team personnel are on site. Data have been downloaded from pilot unit startup through the end of June 2006. These data are plotted in Figure 3.

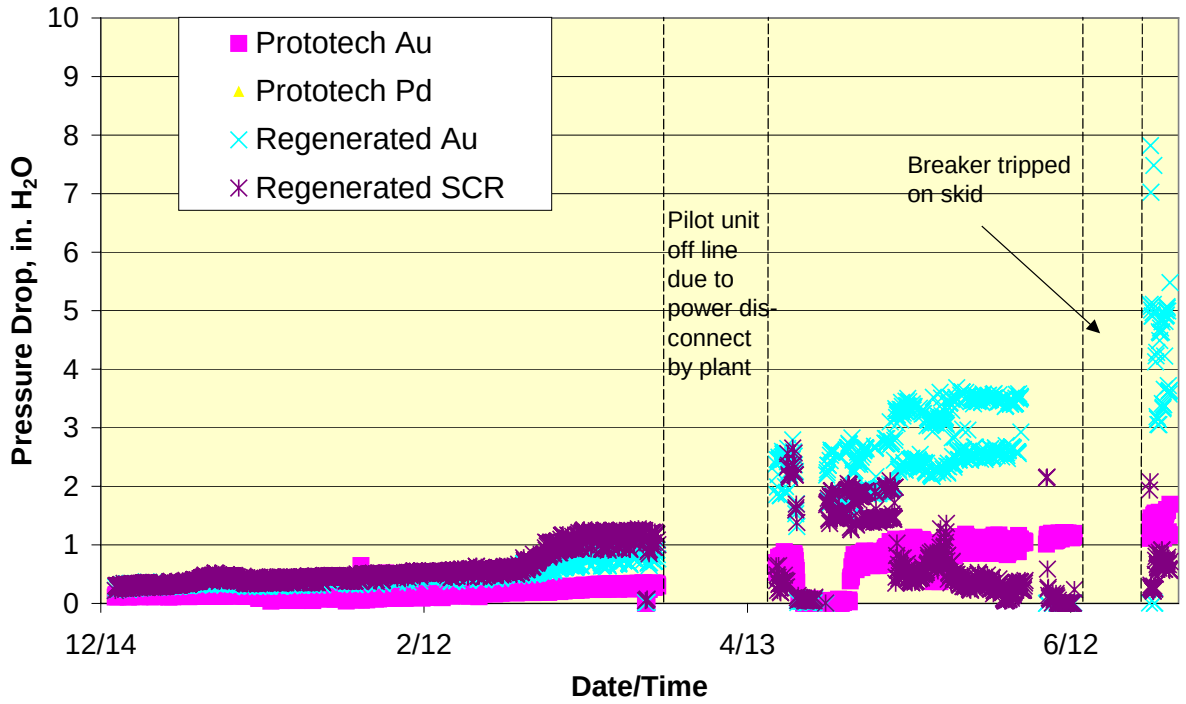


**Figure 3. Pressure Drop Data for the Catalyst Pilot Unit at Plant Yates**

The data show an increase in pressure drop across the catalysts over the past quarter. At the end of the previous quarter, there was a noticeable increase in pressure drop across the two regenerated catalysts. Although the cause of this increase is not known, recall that at Monticello, the regenerated catalyst from a previous site has been harder to keep clean than catalysts that have only been exposed to flue gas from the Monticello site. It may be that interactions between the fly ashes exacerbate tendencies for fly ash to build up.

There were two incidents during the current quarter where power was abruptly interrupted to the catalyst pilot unit. As described earlier for the Monticello pilot, when power is interrupted the flow control valves close, but the flue gas inlet valve remains open. This allows the opportunity for flue gas to cool and condense moisture (and sulfuric acid at this site) in the catalyst chamber. Both of these power interruption episodes appear to have adversely affected catalyst pressure drop performance, particularly for the regenerated gold catalyst. The first interruption was when the host utility reportedly used the power feed to the catalyst pilot unit to provide temporary power for other testing on Unit 3. This interruption lasted about three weeks. The second interruption was for about two weeks, and was cause by a power breaker that tripped in the catalyst pilot unit control panel. The breaker was reset and power loads were redistributed to try to avoid future trips.

Note in Figure 3 that pressure drop data are not shown for the fresh, Prototech palladium catalyst. Since startup, the pressure drop transducer for that catalyst enclosure has read a value near zero. Initially, it was thought that, since all of the catalyst pressure drops were very low, this merely represented minor zero calibration error for that transducer. However, since the other pressure drop values have increased while this value remains near zero, it is apparent that there is a significant calibration error or other problem with this transducer. This problem will be investigated during the next catalyst activity measurement trip.

### *Elemental Mercury Oxidation Activity Performance*

Two catalyst activity measurement trips were conducted at Plant Yates during the quarter. The first was in April and the results of those measurements are summarized in Table 4.

**Table 4. Results of Catalyst Activity Measurements at Plant Yates, April, 2006**

| Catalyst Type | Catalyst Inlet Total Hg* ($\mu g/Nm^3$) | Catalyst Inlet Elemental Hg* ($\mu g/Nm^3$) | Catalyst Inlet Oxidation (%) | Catalyst Outlet Total Hg* ($\mu g/Nm^3$) | Catalyst Outlet Elemental Hg* ($\mu g/Nm^3$) | % Hg Adsorption Across Catalyst | Oxidation Across Catalyst (%) | Catalyst Outlet Oxidation (%) |
|---|---|---|---|---|---|---|---|---|
| New Pd/Al (4/19) | 8.3 | 5.8 | 31 | 7.8 | 1.8 | 6 | 68 | 77 |
| New Au (4/20) | 9.9 | 6.6 | 34 | 7.9 | 0.97 | 20 | 85 | 88 |
| Regenerated Au (4/20) | 9.9 | 6.6 | 34 | 8.1 | 1.6 | 19 | 76 | 80 |
| Regenerated SCR (4/21) | 6.7 | 6.7 | 0 | 7.2 | 1.8 | -8 | 73 | 75 |

*1 $\mu g/Nm^3$ @ 3% $O_2$ = 0.66 lb $Hg/10^{12}$ Btu heat input

The results show that all four catalysts were near adsorption equilibrium (±20%), and were achieving elemental mercury oxidation percentages in the range of 68 to 85% across the catalysts. These percentages are lower than were measured in March, and may reflect adverse effects of the unscheduled pilot unit outage earlier in April. Of the four catalysts, the fresh gold catalyst was clearly the most active. This is somewhat different than the results from the previous quarter, where all four catalysts appeared to be operating at similar activity.

A second catalyst activity measurement trip was made to Plant Yates at the end of June. These results are shown in Table 5. As in Table 4, the results show that all four catalysts were near adsorption equilibrium (±20%). The oxidation percentages range from 70% for the new gold to 76% for the regenerated gold. This is different than in the April trip, where the new gold catalyst was clearly the most active. In these data the new gold was the least active. However, the range in catalyst performance measured in June was probably within experimental error. That is, as in the measurements from the previous quarter, all four catalysts appeared to be operating at similar mercury oxidation activity in June.

**Table 5. Results of Catalyst Activity Measurements at Plant Yates, June, 2006**

| Catalyst Type | Catalyst Inlet Total Hg* ($\mu g/Nm^3$) | Catalyst Inlet Elemental Hg* ($\mu g/Nm^3$) | Catalyst Inlet Oxidation (%) | Catalyst Outlet Total Hg* ($\mu g/Nm^3$) | Catalyst Outlet Elemental Hg* ($\mu g/Nm^3$) | % Hg Adsorption Across Catalyst | Oxidation Across Catalyst (%) | Catalyst Outlet Oxidation (%) |
|---|---|---|---|---|---|---|---|---|
| New Pd/Al (2/21) | 7.0 | 2.7 | 38 | 5.8 | 0.73 | 17 | 73 | 87 |
| New Au (2/22) | 5.7 | 2.7 | 47 | 4.7 | 0.79 | 17 | 70 | 83 |
| Regenerated Au (2/22) | 5.4 | 2.5 | 47 | 4.4 | 0.60 | 20 | 76 | 86 |
| Regenerated SCR (2/23) | 5.2 | 2.2 | 42 | 4.2 | 0.62 | 20 | 71 | 85 |

*1 $\mu g/Nm^3$ @ 3% $O_2$ = 0.66 lb $Hg/10^{12}$ Btu heat input

These results are plotted in Figure 4 below. More data are needed to determine whether the decreases in activity shown in the figure represent a downward trend with general flue gas exposure, or merely represent a “step change” in activity due to adverse effects from the unscheduled outages.

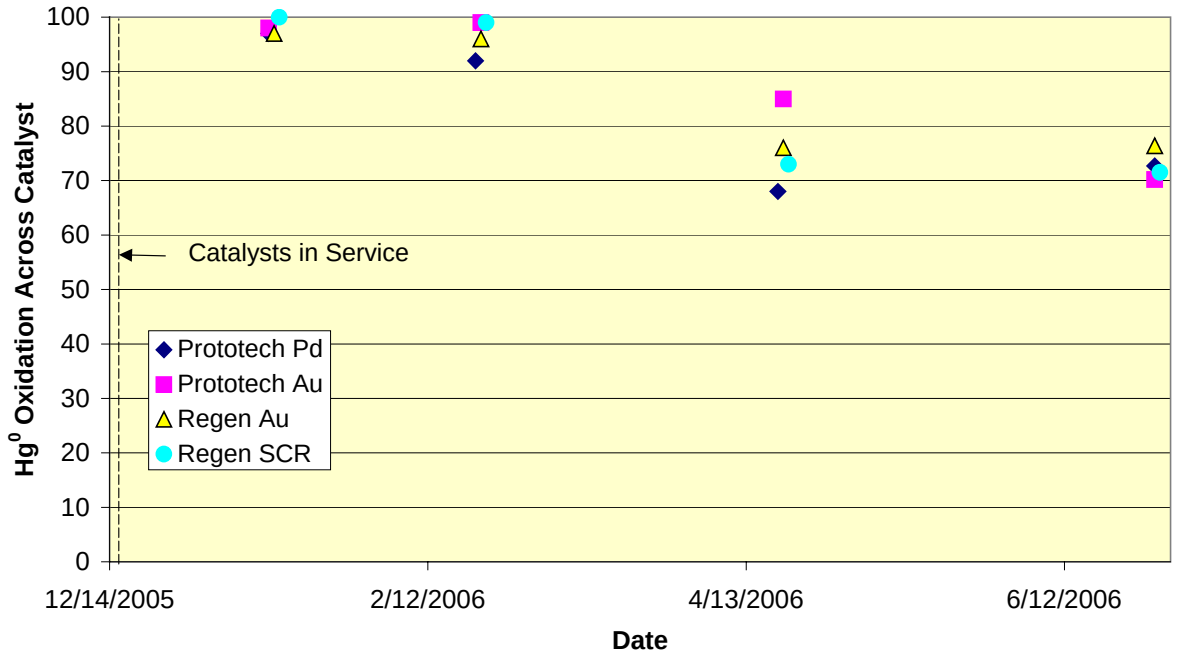


**Figure 4. Catalyst Activity versus Time for the Oxidation Catalysts at Plant Yates**

## Catalyst Pilot Unit Operation at SRP Coronado Station

Unit 2 at Coronado Generating Station is rated at 411-MW of generating capacity, and has a pulverized coal boiler that fires PRB. It has a hot-side ESP for particulate control and a horizontal, natural oxidation, limestone wet FGD system for $SO_2$ control. The PRB coal contains 0.2 to 0.4 wt% sulfur, 0.06 to 0.09 ppm of mercury, and less than 100 ppm of chlorine. The flue gas typically contains 10 to 15 μg/$Nm^3$ of total mercury, of which greater than 90% is in the elemental form.

A two-chamber catalyst pilot unit has been installed at Coronado Station. It is otherwise similar to the catalyst pilot units at Monticello and Yates. As shown in Table 6 below, the Coronado testing has focused on gold-based catalyst, but at two superficial gas velocities through the catalyst chambers. One chamber operates at a superficial gas velocity of 5.5 ft/sec, which is typical of the gold and palladium catalysts in the Monticello and Yates pilot units, while the second chamber operates at a superficial gas velocity of 15 ft/sec. The objective of this test is to determine whether at this plant, where there is not an existing cold-side ESP enclosure in which catalysts could be installed, adequate oxidation performance could be achieved with a smaller cross-section vessel. Johnson Matthey prepared both gold catalysts for the Coronado pilot unit. Note that the 15 ft/sec catalyst chamber has only 72% of the catalyst volume of the 5.5 ft/sec chamber, yet treats the same amount of flue gas.

**Table 6. Characteristics of Catalysts Installed in Pilot Unit at Coronado Station**

| Catalyst Type | Source | Cell Pitch (mm) | CPSI (cells per $in.^2$) | Catalyst Cross-section (in. x in.) | Catalyst Length | Area Velocity (sft/hr) |
|---|---|---|---|---|---|---|
| Gold-based (Au) | Johnson Matthey | 3.2 | 64 | 29.5 x 29.5 | 2 x 6 in. | 37 |
| Gold-based (Au) | Johnson Matthey | 3.2 | 64 | 17.7 x 17.7 | 4 x 6 in. | 51 |

The oxidation catalyst pilot unit at Coronado was started up at the end of March 2006. Catalyst activity measurements were made by SCEM and by the Ontario Hydro method in mid-April, in conjunction with pilot wet FGD tests. The activity of these catalyst is not being measured as frequently as at Monticello or Yates, so there are no additional results since April. The April activity results are discussed below.

### *Catalyst Pressure Drop Data*

Figure 5 shows the pressure drop across the two catalyst chambers at Coronado since startup. These data are being recorded manually, so there are fewer data points that for the other two pilot units. The 15 ft/sec catalyst operates at higher pressure drop than the 5.5 ft/sec catalyst (same velocity as the gold and palladium catalysts in the Monticello and Yates pilot units), as would be expected. Not only is there a velocity effect, but there is twice the overall catalyst depth in the 15 ft/sec catalyst to compensate for the higher velocity. In early June, the pressure drop across the 5.5 ft/sec catalyst appeared to increase for unknown reasons, but the latest data point show complete recovery. The sonic horns on that pilot unit continue to work reliably.

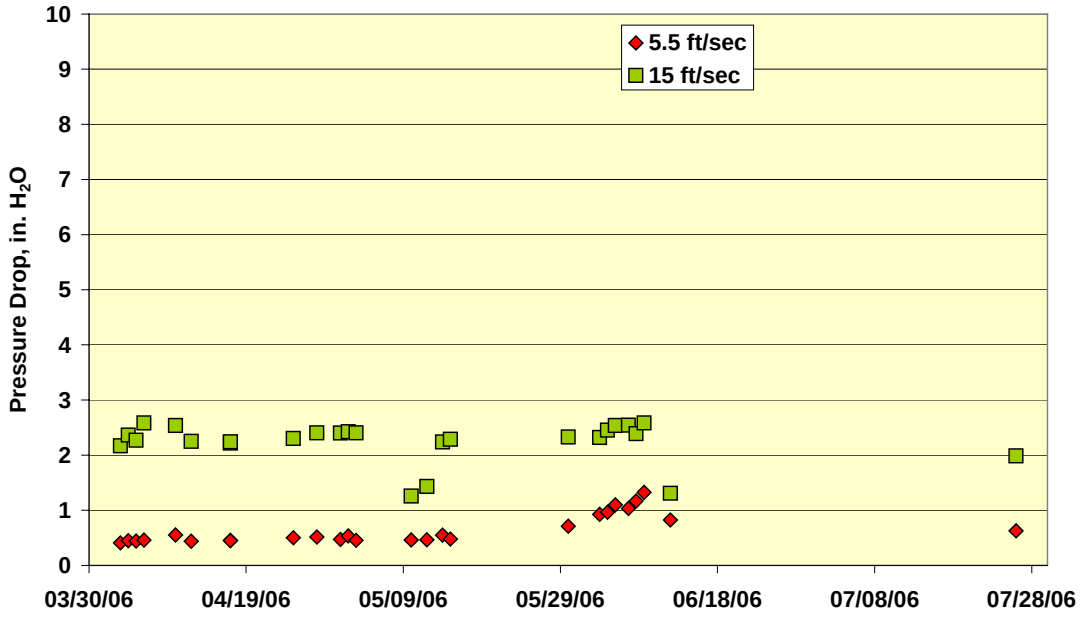


**Figure 5. Pressure Drop Data for the Oxidation Catalysts at Coronado**

*Elemental Mercury Oxidation Activity Performance*

The catalyst activity data were measured both by SCEM and by the Ontario Hydro method in April 2006. The measurement results are inconsistent between the two methods, as shown below in Table 7. The results are presented as mercury oxidation at the catalyst outlet, rather than as a percent oxidation of elemental mercury across the catalyst. However, since the mercury in the inlet flue gas was typically 10% or less oxidized, the two percentage values at the catalyst outlet are not much different.

**Table 7. SCEM and Ontario Hydro Data for the Two Oxidation Catalysts in the Coronado Pilot Unit**

| | Hg Oxidation at Outlet of 5.5 ft/sec Catalyst, % of Total Hg | Hg Oxidation at Outlet of 15 ft/sec Catalyst, % of Total Hg |
|---|---|---|
| SCEM Result | 84 | 97 |
| Ontario Hydro Result | 95 | 88 |

The SCEM data showed the 15 ft/sec catalyst to be the better performing of the two, while the Ontario Hydro data show the 5.5 ft/sec catalyst to be the better performing. The reason for this discrepancy has not yet been resolved. However, it is speculated that stratification of the gas sampled by the SCEM is the cause of the discrepancy. The SCEM sample is withdrawn from a laminar gas flow region just downstream of each catalyst, while the Ontario Hydro measurements were made in a turbulent flow region over 10 feet downstream of the catalysts, a location where the gas sampled should be well mixed.

Although the Ontario Hydro results show the 5.5 ft/sec catalyst to be the better performing of the two, recall that the 15 ft/sec catalyst has only 72% of the catalyst volume of the 5.5 ft/sec catalyst. The fact that the performance of the two catalysts is so similar illustrates the mass transfer benefits that can be derived from operating at higher velocity through the catalysts.

Wet FGD pilot tests were also conducted downstream of one of the catalysts during this April test period. The intent was to operate the scrubber downstream of the better performing catalyst. Since only SCEM results were available at the time, the decision was made to operate the scrubber downstream of the 15 ft/sec catalyst. Based on the Ontario Hydro results, the better choice would have been to conduct these downstream of the 5.5 ft/sec catalyst. Example results from the pilot wet FGD tests are summarized in Table 8 below. The wet FGD test results are still being reviewed, so results from these tests will be presented in greater detail in the next quarterly technical progress report.

**Table 8. Summary of Wet FGD Pilot Tests Downstream of Oxidation Catalysts**

| FGD Operation Mode | Catalyst | $SO_2$ Removal Across Wet FGD, % | Total Hg Oxidation at FGD Inlet, % | Total Hg Capture Across Wet FGD, % | $Hg^{+2}$ Capture Across Wet FGD, % | $Hg^0$ Re-emissions, % of Inlet $Hg^{+2}$ |
|---|---|---|---|---|---|---|
| Limestone Forced Oxidation | 15 ft/sec | 95 | 88 | 83 | 97 | 3 |

The results in Table 8 show that the mercury capture across the pilot wet FGD was 83%, limited in part by the FGD inlet mercury oxidation (88%) and by elemental mercury re-emissions, which lowered the net capture of oxidized mercury to 94%. With the higher performing catalyst in service (95% oxidation) and with the use of an additive such as TMT-15 to control re-emissions, it is likely that 90% mercury capture would have been achieved across the pilot wet FGD system.

Baseline (no catalyst) mercury removal was not measured with the wet FGD pilot unit. However, based on the typical mercury oxidation percentage measured upstream of the oxidation catalyst pilot unit (less than 10%), the mercury removal across the wet FGD system would also be estimated at less than 10%.

## Conclusion

Pilot testing of mercury oxidation catalysts is underway at three coal-fired power plants, one that fires a blend of Texas lignite and PRB coal, a second that fires low-sulfur Eastern bituminous coal, and a third that fires PRB coal. The first two plants have cold-side ESPs for particulate control, while the third has a hot-side ESP.

Results from the Texas lignite/PRB site show significant loss of activity in all four catalysts being tested after about 14 months of flue gas service. The gold catalyst, which has generally been the most active, is currently achieving only about 35% oxidation of elemental mercury as measured by mercury SCEM. However, the pilot unit has been plagued by fly ash buildup, partially due to malfunctioning sonic horns, but also exacerbated by a number of unplanned outages where flue gas was allowed to collect and condense moisture in the catalyst chambers. The remaining efforts at this site will determine the extent to which manually cleaning and thermally regenerating the catalysts can be employed to recover this activity. It is encouraging that a regenerated catalyst from another site, with nearly three years of total flue gas exposure, is currently the most active. This suggests that catalyst regeneration is a viable approach for extending catalyst life and improving process economics.

At the low-sulfur Eastern bituminous coal site, all four catalysts being tested are achieving between 70 and 80% oxidation after seven months of flue gas service. Two of the four catalysts are regenerated catalysts from a previous site, and now have seen nearly two years of flue gas service. Again, it is encouraging that they are as active as the fresh catalysts. Over the next quarter, the catalyst pressure drop and mercury oxidation activity data will need to be watched to determine whether pressure drop increases and activity losses during the current quarter represent ongoing effects of operation in this flue gas, or adverse effects from unscheduled pilot unit outages.

At the PRB site, initial data show that the gold catalyst can achieve 95% oxidation of elemental mercury when operating at a superficial velocity of 5.5 ft/sec, while between 85 and 90% oxidation can be achieved with a lesser quantity of catalyst operating at 15 ft/sec. Wet FGD tests conducted downstream of the 15 ft/sec showed greater than 80% removal of mercury. These results suggest that with the higher-performing 5.5 ft/sec catalyst (or a greater depth of the 15 ft/sec catalyst), it should be possible to achieve greater than 90% mercury removal with a wet FGD system installed on a power plant that fires PRB coal.

These results from the Monticello and Yates pilot units show the importance of keeping fly ash from building up in the catalysts, and suggest that it is best to purge the catalysts of moist flue gas prior to shut down. Note that the pilot unit represents a “worst case” from this perspective, in that moist flue gas can be “dead headed” in the catalyst chambers, while a full-scale unit almost always purges air through the furnace and downstream flue gas path when coming off line.

These results also indicate that thermally regenerated catalysts can be as active as fresh catalysts. Future work is needed to determine how many regeneration cycles a catalyst can undergo before a permanent loss of activity or loss of structural integrity is encountered.

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